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Where host plant goes, galls go too: new records of the Neotropical galling Cecidomyiidae (Diptera) associated with *Calophyllum brasiliense* Cambess. (Calophyllaceae)

Ígor Abba Arriola[1], **João Carlos Ferreira de Melo Júnior**[1*], **Denise Monique Dubet da Silva Mouga**[2], **Rosy Mary dos Santos Isaias**[3] and **Elaine Cotrim Costa**[4]

1 Universidade da Região de Joinville, Laboratório de Anatomia e Ecologia Vegetal, Departamento de Ciências Biológicas, Rua Paulo Maschitzki 10, Zona Industrial Norte, CEP 89219-710, Joinville, SC, Brazil
2 Universidade da Região de Joinville, Laboratório de Abelhas, Departamento de Ciências Biológicas, Rua Paulo Maschitzki 10, Zona Industrial Norte, CEP 89219-710, Joinville, SC, Brazil
3 Universidade Federal de Minas Gerais, Departamento de Botânica, Av. Antonio Carlos, 6627, Pampulha, CEP 31270-901, Belo Horizonte, MG, Brazil
4 Universidade do Estado da Bahia – Campus VIII, Programa de Pós-graduação em Biodiversidade Vegetal, Rua da Gangorra 503, General Dutra, CEP 48608-240, Paulo Afonso, BA, Brazil
* Corresponding author. E-mail: jcmelo_wood@hotmail.com

Abstract: *Calophyllum brasiliense*, a Neotropical species, hosts seven galling Cecidomyiidae reported only for Brazil. Our hypothesis is the distribution of the galling insects associated with *C. brasiliense* is similar to that of the host plant. We checked gall occurrence by field sampling and by searching data in literature and herbaria. Current results indicate that the occurrence of galling Cecidomyiidae associated with *C. brasiliense* extends to 13 Brazilian states, as well as to 11 countries of Neotropical America.

Key words: gall midges; geographic distribution; host-plant; Neotropical region

Galling insects are specialized herbivores, capable of inducing the redifferentiation of specialized plant tissues (Oliveira and Isaias 2010), mainly by hyperplasia and/or cell hypertrophy (Mani 1964). Redifferentiated tissues altogether constitute the galls, abnormal structures that guarantee nutrition and a safe site for development of galling insects and their offspring (Shorthouse et al. 2005). The Cecidomyiidae (Diptera) are the most diverse taxa among the galling insects, with 6,203 described species grouped in 736 genera (Gagné and Jaschhof 2014) with global distribution. In Brazil, there are about 200 species of Cecidomyiidae, with 92% of them monophagous (Carneiro et al. 2009).

The interaction between host plant and galling insect usually results in a gall morphotype with peculiar shape, size, color and indumentum (Isaias et al. 2013, 2014), which reflects the extended phenotype of the gall-inducing insect (Stone and Schönrogge 2003). Actually, galls are believed to be intimate representations of galling insects' diversity (Carneiro et al. 2009). This specificity is well expressed in plants capable of hosting several gall morphotypes, the superhost plants (Isaias et al. 2013, 2014). Distinct morphotypes are irrefutable proof suggesting each plant species has a different set of responses to different insect species' stimuli, which increases diversity of morphotypes (Araújo et al. 2013).

Calophyllum brasiliense Cambess. (Calophyllaceae) is a tree with Neotropical distribution, recorded from Santa Catarina, in the South region of Brazil north to Mexico. In Brazil, *C. brasiliense* occurs in North (Acre, Amapá, Amazonas, Pará, Rondônia, Roraima, and Tocantins states), Northeast (Bahia, Maranhão, Paraíba, Pernambuco, and Piauí states), Mid-West (Goiás, Mato Grosso, and Mato Grosso do Sul states), Southeast (Espírito Santo, Minas Gerais, Rio de Janeiro and São Paulo states), and South (Paraná and Santa Catarina states) regions, occupying Amazon forest, Caatinga, Cerrado, Pantanal and Atlantic Forest biomes (Carvalho 2003; JBRJ 2016; Tropicos 2016).

Calophyllum brasiliense is a superhost of galling cecidomyiids, with five gall morphotypes related to five distinct galling species: two fusiform gall morphotypes, the first induced by *Contarinia gemmae* Maia, 2003 in apical buds, and the latter induced by *Lopesia caulinaris* Maia, 2003 in stems; four leaf galls, a globoid morphotype induced by *L. conspicua* Maia, 2013; a lenticular intralaminar gall induced by *L. elliptica* Maia, 2003; a

fusiform gall induced by *L. linearis* Maia, 2003 (Madeira et al. 2002); and a rolling gall induced by an undescribed species of Cecidomyiidae (Maia 2013; Proença and Maia 2015).

Information on the distribution of galling insects is scarce and mostly limited to the localities where species were originally sampled (Gagné and Jaschhof 2014). This scarcity limits the knowledge on dispersion, evolution and population dynamics of those specialized herbivores. However, information on distribution of *C. brasiliense* has been better documented due to major efforts on plant sampling, studying and systematically adequate records in herbaria. A recent study has documented at four Brazilian sites the distribution of galling cecidomyiids associated with *C. brasiliense*: Rio de Janeiro, São Paulo, Minas Gerais and Goiás states (Proença and Maia 2015), in the Atlantic Forest and Cerrado biomes. We have chosen *C. brasiliense* as a model species to check the viability of using virtual collections of plant material to improve the estimation of geographical distributions of galling insects. Considering the specificity and the life cycles of the involved galling organisms (Mani 1964), our hypothesis is that the galling insects accompany *C. brasiliense* throughout its geographic distribution. Nevertheless, some constraints to the irradiation of galling herbivores should occur. Our objective is to contribute to the knowledge on geographic distribution of the Cecidomyiidae associated with *Calophyllum brasiliense*, taking for granted the Neotropical occurrence of this host plant. Current objectives are: i) verify matching between distribution of Cecidomyiidae related to *C. brasiliense* and host plants; and ii) check and describe the existence of new records for association of *C. brasiliense* and its related galling cecidomyiids throughout virtual and classical herbaria.

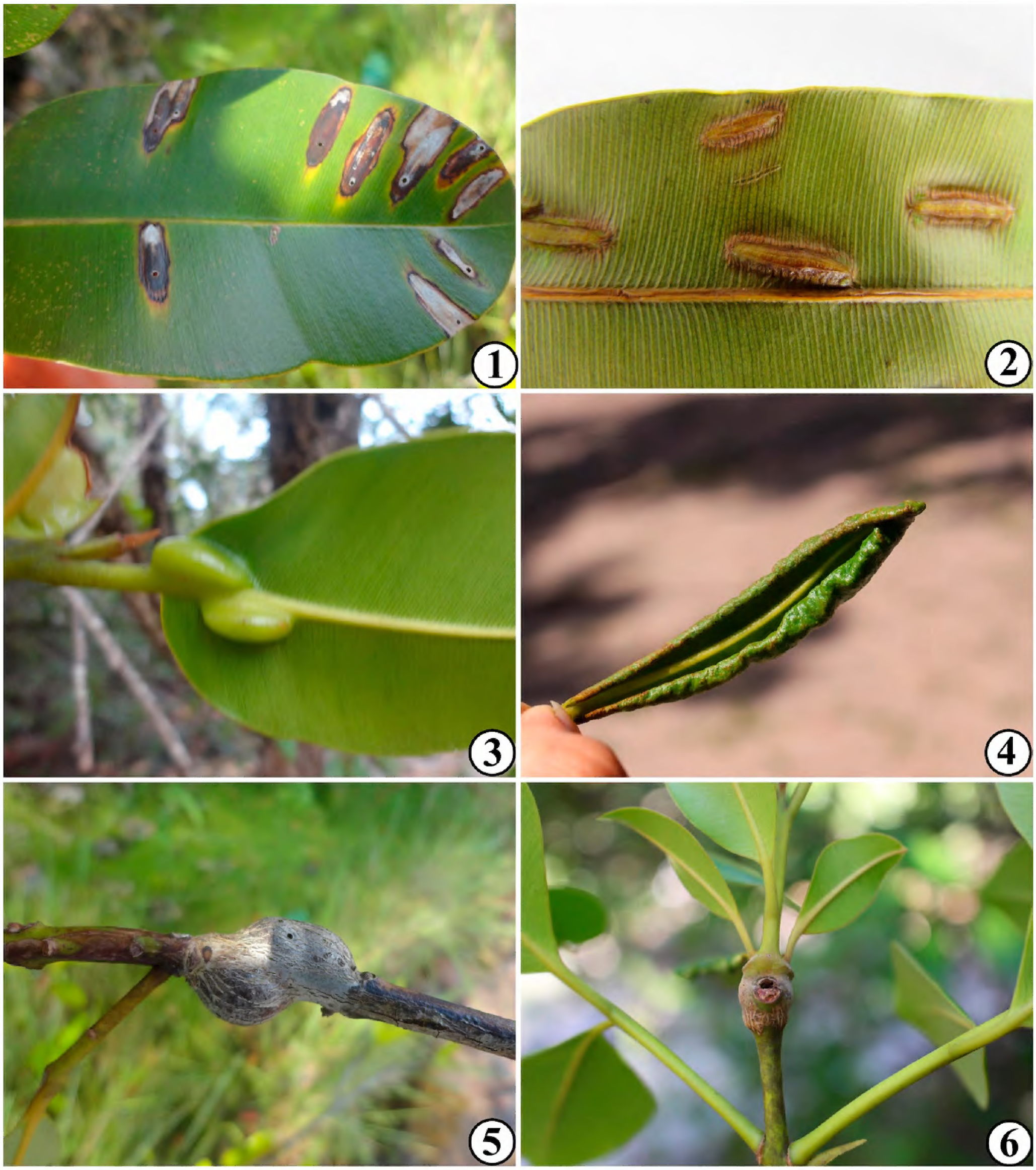
Current data were obtained both from primary and secondary sources. The primary sources were field sampling of host plants at Parque Estadual da Serra dos Montes Altos, municipality of Sebastião Laranjeiras (14°23′41″ S, 043°0′35″ W), Bahia state, from April to March, 2015, and at Parque Estadual Acaraí, municipality of São Francisco do Sul (26°14′36″ S, 048°38′17″ W), Santa Catarina state, from June to August, 2015. Stem and leaf galls were sampled, photographed and described according to Isaias et al. (2013). Vouchers are deposited in Herbarium Joinvillea, of the Universidade da Região de Joinville (JOI) and in the Herbarium of Universidade do Estado da Bahia (HUNEBA), under registration numbers JOI 16568 and HUNEBA 24983, respectively.

The secondary sources were a review of literature data in which *C. brasiliense* and its cecidomyiid-induced galls are reported (Madeira et al. 2003; Maia et al. 2008; Luz et al. 2012; Maia 2013; Julião et al. 2014a, 2014b; Proença and Maia 2015), and direct observation of herbaria (UPBC and UFPR herbaria) and digital collection. Occurrence of galls on plant digitalized exsiccates were visually analyzed in five digital collections examined: FLORA (JBRJ 2016) with 25 records, Missouri Botanical Garden W3 Tropics (Tropicos 2016) with 13 registrations, New York Botanical Garden (NYBG 2016) with 201 records, Virtual Herbaria Austria WU (WU 2016) with 29 records and SpeciesLink (CRIA 2016) with 239 records, totalizing 507 examined exsiccates.

Cecidomyiid species associated with *C. brasiliense* were estimated by the associated gall morphotypes and comparison to literature data (Madeira et al. 2003). Five galling cecidomyiids associated with *Calophyllum brasiliense* in Bahia state (*Contarinia gemnae*, *Lopesia caulinaris*, *L. conspicua, L. elliptica* and an undescribed leaf rolling gall-inducer), and four in Santa Catarina state (*Lopesia caulinaris, L. elliptica*, *L. linearis*, and also the undescribed leaf rolling gall-inducer) were reported (Figures 1–6). Moreover, observation of virtual collections widens the distribution of the Cecidomyiidae associated with *C. brasiliense* to other 11 states in Brazil, totalizing 13 reports for Brazil, five for other countries in South America, five for countries in Central America and one for North America. Comparison of current data to previous published results led to an increase in knowledge (Table 1), easily obtained through observation of gall morphotypes associated with *C. brasiliense* in digitalized exsiccates (Figures 7–12).

The new reports widen the sites of occurrence of *L. linearis* and *L. elliptica* to the area between Mexico (7,264 km away from the type locality, Jurubatiba [RJ]) and Santa Catarina state (855 km), in Brazil. Primary and secondary sources led to the evidence of occurrence of *L. caulinaris* between Costa Rica (5,873 km) and Santa Catarina state, Brazil. Literature data expanded the distribution of *C. gemmae* from Amazonas state (2,960 km) up to São Paulo state (516 km), Brazil. Currently, *L. conspicua* is reported from Amazonas up to Paraná state (804 km). The undescribed Cecidomyiidae associated with clavate and leaf rolling galls were reported in Mato Grosso do Sul and Minas Gerais states, and from Amazonas (2,337 km away from the site of the first report, i.e., Januária, Minas Gerais state) to Santa Catarina state (1,275 km), respectively. Geographical distribution of the galling herbivores associated with *C. brasiliense*, previously restricted to some Brazilian states is currently widened to the Neotropical region (Figure 13).

Occurrence of *C. brasiliense* in Brazilian states of Acre and Piauí, and in Belize, El Salvador, Haiti, Nicaragua, Porto Rico and Venezuela were also reported from herbaria sources. The exsiccates for these eight sites where *C. brasiliense* occurs are not available in digital format, which end up in some difficulties in documenting the geographic distribution of the galling Diptera associated with *C. brasiliense* over the whole of the Neotropics.



Figures 1–6. Gall morphotypes associated with *Calophyllum brasiliense* Cambess. (Calophyllacae) in Bahia and Santa Catarina States. **1.** Lenticular intra-laminar gall induced by *Lopesia elliptica* Maia, 2003. **2.** Leaf fusiform gall induced by *Lopesia linearis* Maia, 2003. **3.** Leaf globoid gall induced by *Lopesia conspicua* Maia, 2003. **4.** Leaf rolling gall induced by unknown Cecidomyiidae. **5.** Stem fusiform gall induced by *Lopesia caulinaris* Maia, 2003. **6.** Bud globoid gall induced by *Catarinia gemnae* Maia, 2003.

The knowledge on distribution of the cecidomyiids associated with *C. brasiliense* up to 2015 was restricted to Rio de Janeiro, São Paulo, Minas Gerais and Goiás states, in Brazil, with six gall morphotypes recorded (Maia 2013; Proença and Maia 2015). A seventh morphotype (clavate leaf gall), also induced by a Cecidomyiidae, was reported for Minas Gerais and Mato Grosso do Sul states (Luz et al. 2012; Julião et al. 2014a). This distribution is widened to the Amazonas state (Julião et al. 2014a), which was not included in

Table 1. Previous and new records of galls on *Calophyllum brasiliense* Cambess. (Calophyllaceae) in the Neotropical region.

Country	State / department	Municipality	Location	Coordinates	Environment	Morphotype / host organ	Reference
Bolivia	Santa Cruz	Intermunicipal region (Ichilo Province)	Parque Nacional Amboró	17°32′ S, 063°52′ W	Rainforest lowland	Fusiform/leaf; globoid/stem; intralaminar lenticular	New records[3]
Brazil	Amapá	Oiapoque	Not Available	03°31′ N, 053°17′ W	Not Available	Globoid/stem; intralaminar lenticular	New records[3]
Brazil	Amazonas	Intermunicipal Region	Reserva de Desenvolvimento Sustentável Amanã	02°26′ S, 064°47′ W	Amazon Forest (*Igapó* floodplains)	Leaf rolling; fusiform/leaf; globoid /bud; globoid/stem; globoid/leaf; intralaminar lenticular	Julião (2007); Julião et al. (2014b)[2]
Brazil	Bahia	Sebastião Laranjeiras	Parque Estadual da Serra dos Montes Altos	14°23′ S, 043°0′ W	Cerrado (Riparian forest)	Leaf rolling; globoid/bud; globoid/stem; globoid/leaf; intralaminar lenticular	New records[1]
Brazil	Espírito Santo	Linhares	Reserva Natural Companhia Vale do Rio Doce	Not Available	Lownland	Fusiform/leaf	New records[3]
Brazil	Goiás	Pirenópolis	Cachoeira da Meia-Lua	15°51′ S, 048°57′ W	Cerrado (Riparian forest)	Leaf rolling; globoid/bud; globoid/stem; globoid on leaf; intralaminar lenticular	Proença and Maia (2015)
Brazil	Mato Grosso	Santa Terezinha	Not Available	Not Available	Cerrado (Murundu fields)	Fusiform/leaf; intralaminar lenticular	New records[3]
Brazil	Mato Grosso do Sul	Corumbá	Passo da Lontra (Pantanal do Miranda-Abobral)	19°34′ S, 057°00′ W	Semideciduous forest (Pantanal floodplains)	Clavate/leaf; fusiform/leaf	Julião et al. (2014a)[2]
Brazil	Minas Gerais	Januária	Área de Proteção Ambiental Rio Pandeiros	15°29′ S, 044°21′ W	Cerrado-Caatinga transition	Clavate/leaf; leaf rolling; globoid/bud; globoid/stem; globoid/leaf	Luz et al. (2012)[2]
Brazil	Minas Gerais	São Tomé das Letras	Gruta do Sobradinho and Vale das Borboletas	22°42′ S, 044°58′ W	Atlantic Forest	Leaf rolling; fusiform on leaf; globoid/bud; globoid/stem; globoid/leaf; intralaminar lenticular	Maia (2013)
Brazil	Pará	Moju	Vila Lírio Campos	02°11′ N, 048°45′ W	Not Available	Fusiform/leaf; intralaminar lenticular	New records[3]
Brazil	Paraná	Paranaguá	Piaçaguera (Baía Paranaguá)	25°28′ S, 048°28′ W	Mangrove	Fusiform/leaf; globoid/leaf; intralaminar lenticular	New records[4]
Brazil	Pernambuco	Not Available	Bancos do Rio Preto	Not Available	Riparian forest	Intralaminar lenticular	New records[3]
Brazil	Rio de Janeiro	Carapebus	Parque Nacional de Jurubatiba	22°00′ S – 22°23′ S, 041°15′ S – 041°45′ W	Restinga	Fusiform/leaf; globoid/bud; globoid/stem; globoid/leaf; intralaminar lenticular	Madeira et al. (2002)
Brazil	Rio Grande do Norte	Canguaretama	Estrada BR 101	06°11′ S, 035°07′ W	Riparian forest	Fusiform/leaf; intralaminar lenticular; globoid/leaf	New records[3]
Brazil	Rondônia	Chupinguaia	Not Available	Not Available	Not Available	Fusiform on leaf; intralaminar lenticular	New records[3]
Brazil	Roraima	Caracaraí	Parque Nacional do Viruá	Not Available	Not Available	Fusiform/leaf	New records[3]
Brazil	Santa Catarina	São Francisco do Sul	Parque Estadual Acaraí	26°17′ S, 048°33′ W	Restinga	Leaf rolling; fusiform/leaf; globoid/stem; intralaminar lenticular	New records[1]
Brazil	Maranhão	São Luís	Ilha de São Luís	02°34′ S, 044°12′ W	Atlantic Forest	Leaf rolling; intralaminar lenticular	New records[3]
Brazil	São Paulo	Bertioga	Itaguaré and Guaratuba	23°51′ S, 046°08′ W	Restinga	Fusiform/leaf; globoid/bud; globoid/stem; intralaminar lenticular	Maia et al. (2008)
Brazil	Tocantins	Formoso do Araguaia	Not Available	11°48′ S, 049°31′ W	Cerrado *stricto sensu*	Intralaminar lenticular	New records[3]
Colombia	Antioquia	Turbo	Atrato River Mouth, Urabá Gulf	Not Available	Mangrove	Fusiform/leaf	New records[3]
Costa Rica	Heredia	Horquetas de Sarapiqui	Arredores do rio Atelopos	10°17′ N, 084°02′ W	Primary Forest	Fusiform/leaf; globoid/stem; intralaminar lenticular	New records[3]
Cuba	Not Available	Not Available	Cuba Oriental	Not Available	Not Available	Fusiform/leaf; intralaminar lenticular	New records[3]
Guatemala	Péten Department	Santa Helena and San Francisco	Not Available	Not Available	Wetland Tropical Forest	Intralaminar lenticular	New records[3]
Guyana	Upper Takutu-Upper Essequibo	Not Available	Not Available	Not Available	Not Available	Fusiform/leaf; intralaminar lenticular	New records[3]

Continued

Table 1. *Continued.*

Country	State / department	Municipality	Location	Coordinates	Environment	Morphotype / host organ	Reference
Mexico	Oaxaca	Matías Romero Avendaño	Ubero	Not Available	Submontane Forest	Fusiform/leaf; intralaminar lenticular	New records[3]
Paraguay	Amambay	Not Available	Sierra de Amambay	Not Available	High forest	Fusiform/leaf; intralaminar lenticular	New records[3]
Peru	Loreta	Saboya	Maynas Province	03°50′ S, 074°10′ W	Wetland Tropical Forest	Fusiform/leaf; intralaminar lenticular	New records[3]
Dominican Republic	Dajabón Province	Dajabón	Banks of Rio Chacuey	19°32′ N, 071°42′ W	Riparian forest	Intralaminar lenticular	New records[3]
Trinidad and Tobago	Saint George	Arima	Not Available	10°37′ N, 061°16′ W	Not Available	Fusiform/leaf	New records[3]

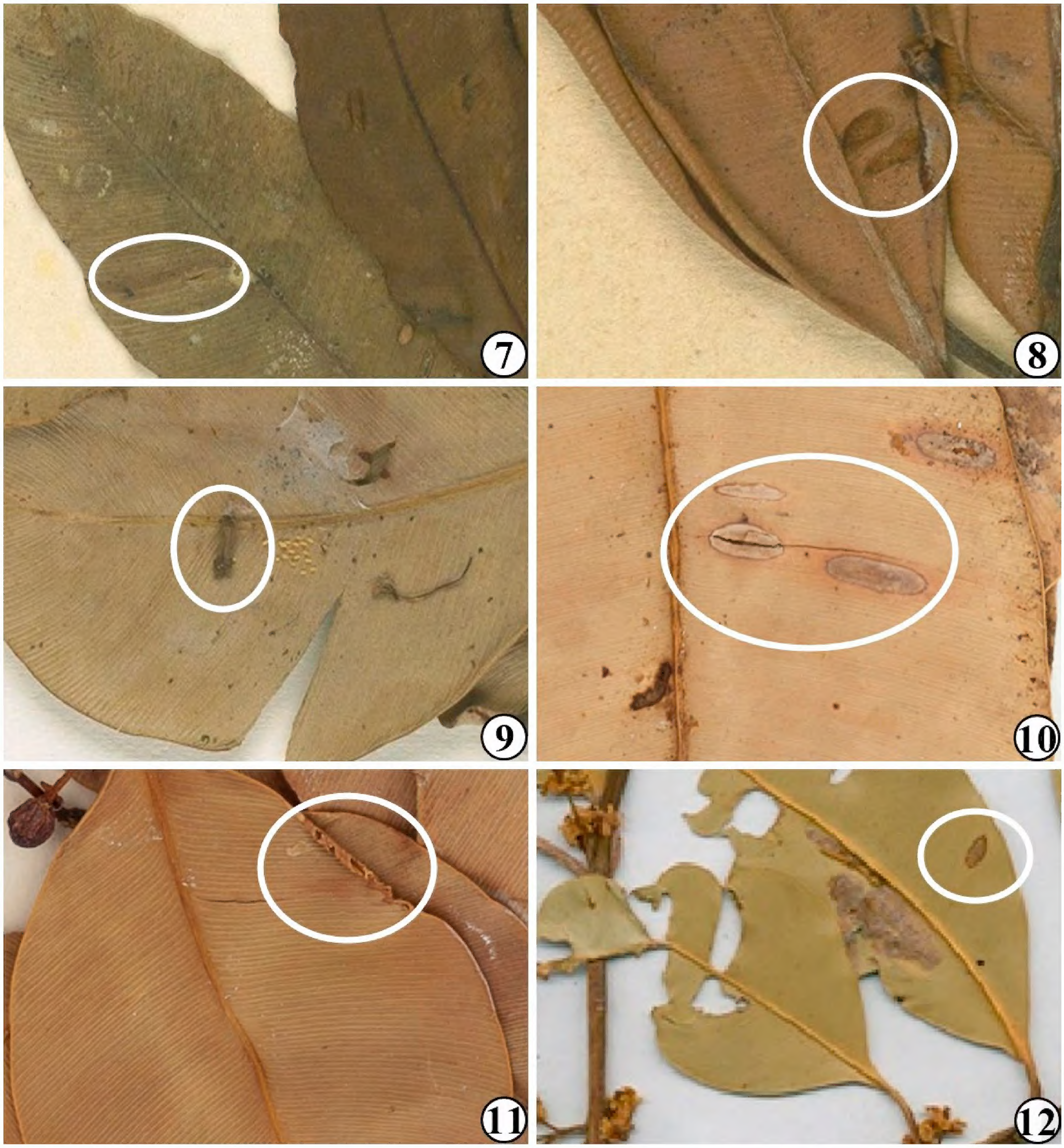
Legend: New records from primary data[1], bibliography[2], virtual[3] and visited herbaria[4].

the last report of cecidomyiid distribution (Proença and Maia 2015).

The distribution of cecidomyiids associated with *C. brasiliense* reflects this family's overlapping distribution with the host plant. As we are dealing with species-specific interactions, we can confidently assume that host plant geographical distribution influences the geographical distribution of its associated galling herbivores. The wide geographical distribution of *C. brasiliense* reflects in a wide geographical distribution for its associated herbivores. Geographical distribution analysis of the seven cecidomyiid species associated with *C. brasiliense* in the Neotropical region (Gagné and Jaschhof 2014) provides evidence that the clavate gall morphotype has the most restricted distribution (Minas Gerais and Mato Grosso do Sul states); *C. gemmae* (from São Paulo to Amazonas state), *L. conspicua* (Paraná and Amazon states) and the leaf intralaminar gall (Santa Catarina and Amazon states) extends being the southern tropical region. *L. elliptica* and *L. linearis* have a wide distribution (Santa Catarina to México and the Caribean), and *L. caulinaris* has the widest distribution of all (from Santa Catarina state in Brazil to Costa Rica). Consequently, there are four species restricted to Brazil, two previously described by Gagné and Jaschhof (2014), *C. gemmae* and *L. conspicua,* and two herein recorded for the first time, inducers of leaf rolling gall and of clavate gall morphotypes.

Latitudinal distribution of cecidomyiida associated with *C. brasiliense* provides evidence that five species occur in the Subtropical region (Santa Catarina and Paraná states), seven in the south tropical region (from São Paulo to Amazonas state), and three species in the north region (Amapá and Roraima states up to Mexico). Geographical distribution of Cecidomyiidae overlaps to the distribution of *C. brasiliense*. A reduction and a turnover of cecidomyiid species are observed towards the northern hemisphere, probably due to constraint of phenotypic plasticity (Valladares et al. 2007) imposed both on the host plant and galling herbivores. This hypothesis is corroborated by the report of *Trioza* sp. (Tryozidae: Hemiptera) as the inducer of the marginal leaf rolling gall morphotype in *C. brasiliense*, exclusively in Costa Rica (Martin and Hollis 1992). In addition, formation of ecotypes of host plants due to their wide geographical distribution may also be a start point for the irradiation of galling organisms. Anyway, knowledge on the biodiversity of south hemisphere increased due to efforts in sampling along Neotropical countries, which is also true for the Cecidomyiidae.

The analyses of the model species *C. brasiliense* and its associated galling cecidomyiids have proved the usefulness of virtual herbaria not only to document plant distribution, but also to document host plant-galling herbivore associations. The better the collection



Figures 7–12. Gall morphotypes associated with *Calophyllum brasiliense* Cambess. (Calophyllacae) observed in exsicates of virtual herbaria. **7.** Lenticular intralaminar gall induced by *Lopesia elliptica*. Material from Mexico (W 1938-0003275). **8-10, 12.** Leaf fusiform gall induced by *Lopesia linearis*. **8.** Material from Cuba (W 1889-0081162). **9.** Material from Guatemala (W 1968-0020084). **10.** Material from Peru (NY 00455609). **12.** Material from Tocantins, Brazil (HUTO 1959).**11.** Leaf rolling gall induced by a Cecidomyiidae. Material from Maranhão State, Brazil (W 1938-0003275).

is, the better the estimative is made, which is herein observed for New York Botanical Gardens digital collection. Current estimation widens the geographical distribution of Cecidomyiidae-*C. brasiliense* systems throughout Brazilian biomes.

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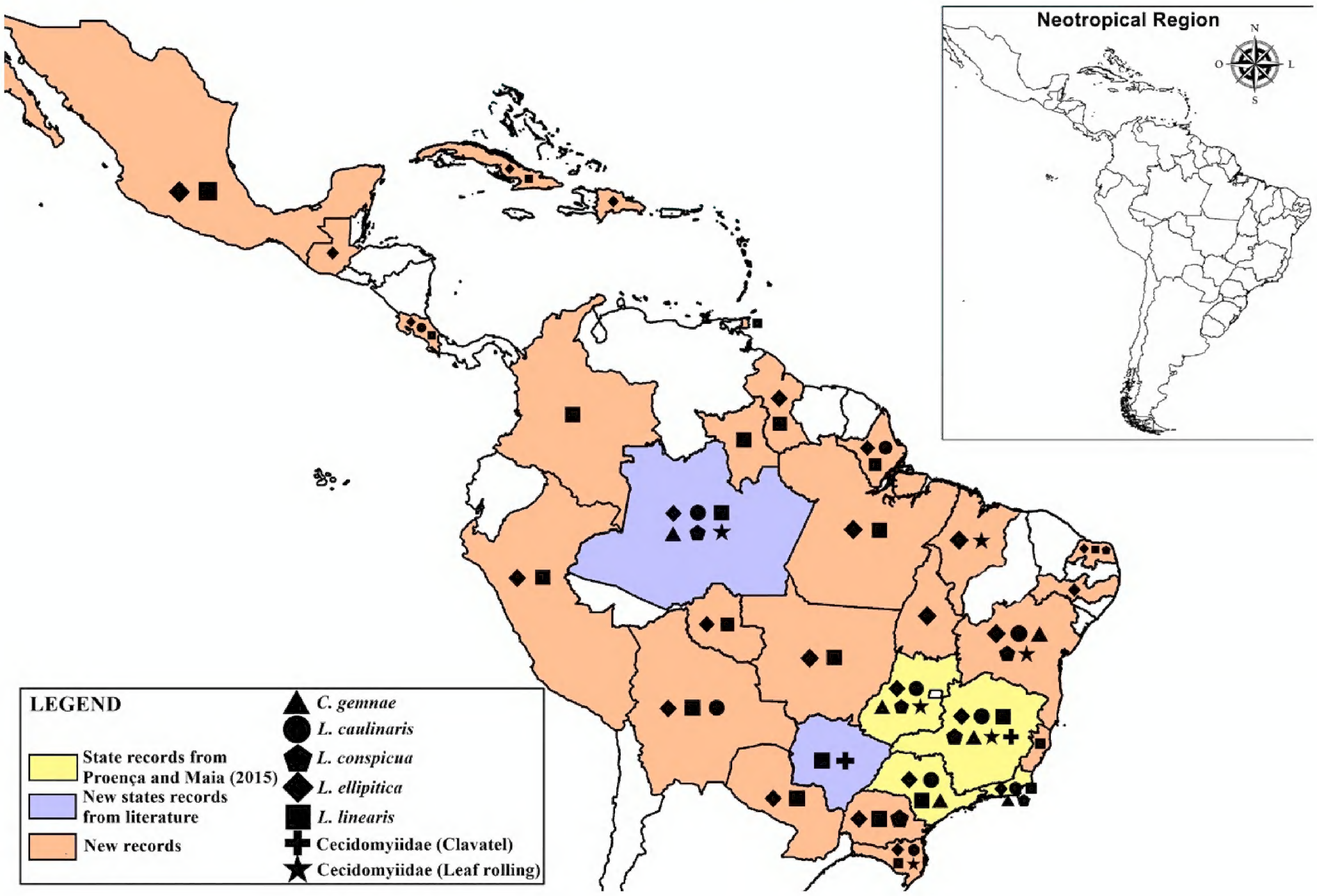

Figure 13. Geographical distribution of the Cecidomyiidae (Diptera) associated with *Calophyllum brasiliense* Cambess. (Calophyllaceae) in Neotropical region.

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